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(54) Oxidized oligosaccharides

(57) The invention provides oligosaccharides having molecular weights in the range 1000 to 50,000 and obtained by partial hydrolysis of oxidized polysaccharides such as oxidized regenerated cellulose (ORC). The oligosaccharides are useful as or in wound dressings, and for binding peptides or proteins.

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OXIDIZED OLIGOSACCHARIDES

This invention relates to oxidized oligosaccharides such as oligosaccharides of oxidized regenerated cellulose (ORC). The invention also relates to the use of oxidized oligosaccharides in wound dressings and other medical and pharmaceutical applications, and to methods for preparing oxidized oligosaccharides.

ORC has long been manufactured and used medically to achieve haemostasis, and as a barrier material to prevent adhesions following surgery. A key feature of ORC is that it is absorbable when implanted in the body, whereas cellulose is not. ORC is resorbed by hydrolytic cleavage of the polymer to yield small oligosaccharides which are metabolized and eliminated from the body. Oxidation of cellulose to yield 10 to 21% carboxyl groups by weight of the cellulose allows substantially complete absorption of the material within two to three weeks following implantation.

ORC is manufactured by exposure of cellulose to an oxidizing agent such as dinitrogen tetroxide, as described in US-A-3122479. The physical form of cellulosic material is not critical. For example, the cellulosic film, paper, sponge and cloth may all be oxidized to yield ORC. However, the commercially preferred material is a woven or knitted fabric. ORC in the form of a knitted fabric is available under the Trade Mark SURGICEL for use as an absorbable haemostat, and ORC is also available under the Trade Mark INTERCEED for use as an adhesion barrier.

Polysaccharides other than cellulose may also be oxidized to yield medically useful haemostatic materials. Such other polysaccharides include microbial polysaccharides such as dextran, gellan gum and xanthan gum; polysaccharides derived from plants, for example agar, starch, konjac, carrageenan, guar gum, inulin and pectin; and polysaccharide

derivatives such as carboxymethyl cellulose, methylhydroxypropyl cellulose, cellulose acetate, methyl cellulose, and ethyl cellulose.

It has been proposed to combine ORC with other materials for use as wound dressings. For example, US-A-2517772 (Doub *et al*) discloses dressings formed from ORC impregnated with thrombin. However, ORC is significantly acidic. The surface pH of a fully water-saturated piece of ORC fabric may be as low as 1.7. Many proteinaceous agents, such as thrombin, are highly acid-sensitive, and are inactivated immediately on contact with such a matrix. Accordingly, Doub *et al* teach that ORC should be neutralized prior to impregnation with thrombin. Calcium acetate, sodium bicarbonate, ammonia and alcoholic ethylamine are given as examples of suitable neutralizing agents, but Doub *et al* warn that ORC should not be neutralized to such a degree that it loses its fibrous nature when placed in water because of solution or gelling and disintegration.

EP-A-0437095 discloses that the use of aqueous solutions of sodium bicarbonate to neutralize ORC cloth results in a cloth which is partially gelled, distorted from its original size and very weak with little integrity. The tensile strength of the cloth is said to be too low for practical use such as, for example, a haemostat. Similar results are said to be obtained with the use of strongly basic aqueous sodium hydroxide and ammonium hydroxide solutions. EP-A-0437095 accordingly teaches a process for preparing a storage stable, non-irritating and therapeutic neutralized oxidized cellulose product comprising the steps of contacting an acid oxidized cellulose material with an alcohol and water solution of a slightly basic chloride-free salt of a weak acid to elevate the pH of the cellulose material to between 5 and 8; washing the elevated pH cellulose material with alcohol to remove excess salt and water; and drying the cellulose material to remove alcohol.

It has now been found that ORC and other oxidized polysaccharides can be partially hydrolysed under mild alkaline conditions to yield oligosaccharides which have a number of medically useful properties.

Accordingly, the present invention provides an oxidized oligosaccharide composition having an average molecular weight in the range 1000 to 50000 daltons.

In particular, the oxidized polysaccharides of the present invention bind therapeutically useful agents, and such bound agents can then be released in high yield. The oxidized oligosaccharides of the present invention can therefore be used in pharmaceutical compositions, for example in wound dressings, to deliver such agents to a wound site. The therapeutically useful agents which are bound by oxidized oligosaccharides include pharmaceutically active peptides and proteins, preferably growth factors such as PDGF AB, PDGF BB, TGF-β1, TGF-β2, TGF-β3, basic FGF, acidic FGF and possibly EGF and TGF-α.

Without wishing to be bound by any theory, it is thought that the anionic carboxylate groups on the oxidized oligosaccharides complex to cationic amine groups on the peptides and proteins. Complexation to therapeutically active agents having anionic groups can also readily be achieved, for example, by use of polyvalent metal ions such as Ca^{2+} or Zn^{2+} as ionic cross-linking agents.

A further advantage of the oxidized oligosaccharides of the present invention is that they may be intimately combined with other materials such as proteins and other polysaccharides (with or without chemical cross-linking) to form compositions having novel properties. For example, oxidized oligosaccharides may be combined with hyaluronic acid, chitosan, or an alginate (particularly sodium alginate, calcium alginate or a mixed sodium/calcium alginate) to form novel haemostatic compositions.

Alternatively, composites of oxidized oligosaccharides with other oligosaccharides, polysaccharides or proteins may be used as controlled release matrices for a variety of therapeutic agents such as antiseptics, antibiotics, protein growth factors, anti-inflammatories, analgesics, proteinase inhibitors such as aprotinin or the hydroxamic acids. The oxidized oligosaccharides of the present invention may be combined with a desired therapeutic agent while in solution (the therapeutic agent being either in solution in suspension), and the oligosaccharide may be then be removed from solution by suitable means, to yield a material in which the therapeutic agent is substantially uniformly distributed. Alternatively, the solvent may be removed, e.g. by freeze-drying.

Oxidized oligosaccharides may also be cross-linked so as to allow the formation of three-dimensional structures. For example, oxidized oligosaccharides can be dissolved in water to which a very low concentration of pepsin-solubilized collagen is added. If carbodiimide is then added as a cross-linker, the collagen acts as a bridging group between the oligosaccharides, such that a three-dimensional structure can be obtained by freeze drying.

The oxidized oligosaccharides of the present invention preferably have a molecular weight of at least 1000 daltons, and generally less than 100000. Most usually, the molecular weight will be less than 5000 to 30000 daltons. (It will be understood that the oxidized oligosaccharides of the present invention will generally form a mixed population of different sized molecules. Accordingly, references herein to oxidized oligosaccharides having a particular molecular weight range, and more preferably at least 90% by weight, of the molecules fall within the specified range.)

In one embodiment, oligosaccharides according to the invention are derived from insoluble oxidized polysaccharides and are of such a molecular weight that they

are soluble at neutral and alkaline pH, but insoluble at acid pH. Such oligosaccharides can be readily recovered from solution merely by reducing the pH, so causing them to precipitate. Alternatively, however, oxidized oligosaccharides can be recovered from solution by transferring them to a solution which does not contain any other non-volatile components, and then evaporating the solvent. For example, oxidized oligosaccharides can be isolated using an ion exchange solid phase extraction column (such as a phenyl boronic acid solid phase column, previously activated with methanol and equilibrated with dilute acetic acid), and then eluted with dilute (e.g. 0.1M) ammonium hydroxide solution.

Preferably, the oxidized oligosaccharides of the present invention have a carboxyl content of from 5 to 25% by weight, and more preferably from 8 to 14% by weight. The carboxyl content of the oligosaccharides is determined as follows:

A sample of oxidized oligosaccharide (approximately 0.2g) is dissolved in 0.5M sodium hydroxide (5ml) and a couple of drops of 0.1% phenolphthalein indicator solution are added. The excess sodium hydroxide is back-titrated with 0.1M HCl to the phenolphthalein end point (red to clear). A blank value is determined by titrating 5ml 0.1M sodium hydroxide with 0.1M HCl. The value for carboxyl content is calculated using the equation:

$$C = \frac{4.5 \times (B-S) \times M}{W}$$

wherein:

C = percent carboxyl content

B = volume of standard HCl to titrate blank (ml)

S = volume of standard HCl to titrate sample (ml)

M = morality of standard HCl

W = dry weight of sample (g)

(4.5 = milliequivalent weight of carboxyl x 100)

The present invention also provides a method of preparing an oxidized oligosaccharide, comprising treating an oxidized polysaccharide having a molecular weight of at least 50000 (more usually at least 100000, e.g. more than 30000) with an aqueous alkaline solution at a temperature and for a period of time sufficient to result in partial hydrolysis of said polysaccharide, and then recovering the resulting oxidized oligosaccharide from solution, e.g. by adjusting the pH to 7 or less. The alkaline solution is conveniently a solution of an alkali metal hydroxide or bicarbonate, e.g. sodium hydroxide or sodium bicarbonate, although other alkalis (e.g. aqueous ammonium hydroxide) can also be used. It will be understood that the treatment conditions (and particularly the pH) are dependent on the desired molecular weight range for the resulting product. However, appropriate conditions can readily be determined in any particular case by routine experiment. By way of example, oxidized regenerated cellulose may be hydrolyzed in 1M to 8M sodium hydroxide at a temperature of from 0°C to 50°C for 5 to 120 minutes to yield oligosaccharides in the molecular weight range 1000 to 20000 daltons, or with 0.01M to 1M sodium bicarbonate at 0°C to 50°C for 10 hours to 10 days to yield oligosaccharides in the molecular weight range 7000 to 50000.

The hydrolytic reaction can be stopped by the addition of an acid, such as a mineral acid, until the solution is approximately neutral. Concentrated hydrochloric acid can conveniently be used.

The invention is further described by the following Examples.

Example 1

A solution of ORC was prepared by dissolving Surgicel™ fabric at a concentration of 20mg/ml in 6M sodium hydroxide.

The solution was incubated at 37°C for 45 minutes after which the reaction was stopped by adding 6M HCl until precipitation occurred and the pH changed from alkaline to pH7 or less. The precipitate was allowed to settle overnight, and then the excess liquid was removed. The precipitate was dialysed against water in tubing with a 1000 molecular weight cut off, then freeze dried to product a powder.

The molecular size of the oligosaccharide, determined by gel electrophoresis and by high performance liquid chromatography, showed a range extending from approximately 1000 to 15000 daltons.

Example 2

A solution of ORC was prepared by dissolving Surgicel™ fabric at a concentration of 10mg/ml in 0.1M sodium bicarbonate. The solution was incubated at 37°C for a few days (2-3) until all the ORC has dissolved. The reaction was stopped by adding 6M HCl until precipitation occurred and the pH changed from alkaline to pH7 or less. The precipitate was allowed to settle overnight and then the excess liquid removed. The precipitate was dialysed against water in tubing with a 1000 molecular weight cut off, then freeze dried to product a powder.

The molecular size, determined as described above, showed a range from approximately 1000 to 30000 daltons.

Example 3

Oxidized carboxymethyl cellulose sponge was prepared as follows:

Into 500 grams of water is added with stirring 7.5 grams of carboxymethylcellulose (CMC) from Aqualon Corporation. When the polymer is dissolved the solution is allowed to deaerate overnight to remove trapped air bubbles. The solution is poured into trays 3x4x¼ inch, and freeze

dried for 24 hours in a lyophilizer. Soft, white, water soluble CMC sponges are obtained from this procedure.

The oxidation of the CMC sponges is accomplished by placing 5.8 grams of dry sponges into a resin kettle to which is attached a small flask containing 8 grams of nitrogen tetroxide. The nitrogen tetroxide is allowed to evaporate from the small flask into the resin kettle and envelope the CMC sponges in an atmosphere of gas. The sponges are kept in the resin kettle for 48 hours after which time the gas is evacuated to caustic trap and the sponges are removed and placed in 500ml of water. The oxidized CMC sponges are not soluble in water. They are washed with water for 15 minutes then placed in fresh water for another wash. This washing of the oxidized sponges is repeated until the pH of the wash water is above 3. The white oxidized carboxymethylcellulose sponges are dried by placing them in 100% isopropyl alcohol for 15 minutes. This is repeated for a total of 2 washes then the sponges are allowed to air dry. The oxidized CMC sponges are soft and conformable and will absorb 14 times their weight in isotonic saline. They are soluble in 0.5N sodium hydroxide and are characterized by their carboxylic acid content which is found by titration to be 26.3%.

A solution of the oxidized carboxymethyl cellulose was prepared by dissolving the sponge material at a concentration of 10mg/ml in 0.1M ammonium hydroxide. The solution was incubated at 37°C for 2 hours, and the reaction was then stopped by the addition of 6M HCl until precipitation occurred. The precipitate was collected and dialysed extensively against distilled water in tubing with a 1000 dalton molecular weight cut off, then freeze dried to produce a powder.

The molecular weight was determined by gel electrophoresis and found to be 1000 and 30000 daltons.

Example 4

Methyl cellulose was oxidized by a procedure analogous to that described in Example 3, and a solution was prepared by dissolving the oxidized material at a concentration of 20mg/ml in 6M sodium hydroxide and incubating at 37°C for 45 minutes. The solution was centrifuged to remove any undissolved material, and the oligosaccharides were precipitated out of solution by the addition of 6M HCl. The precipitate was collected and dialysed extensively against distilled water in tubing with a 1000 dalton molecular weight cut off.

The molecular weight was determined by gel electrophoresis and found to be between 1000 and 5000 daltons.

Example 5

A phenyl boronic acid (PBA) solid phase extraction column (Bond Elut, Varian Associates), containing 100mg of sorbent material with a 10ml reservoir, was activated using 10ml of methanol to wet the column, followed by 10ml 0.1M acetic acid to equilibrate the column at the correct pH.

ORC solution was prepared by dissolving 1g of Interceed™ material in 100ml 6M sodium hydroxide solution. After the Interceed™ material had fully dissolved, the solution was acidified to pH 3.0 and any precipitate was removed by centrifugation. The supernatant was taken, and 2ml was passed through the activated PBA column. The column was then washed with 2ml 0.1M acetic acid and 4x2ml portions of distilled water to remove any salt or other endogenous material. The ORC oligosaccharides were eluted from the column using 2x2ml portions of 0.1M ammonium hydroxide. the portions were pooled, frozen and lyophilised to produce a powder. After separation of the oxidized oligosaccharides by ion-exchange chromatography, mass spectrographic analysis shows them to have a molecular weight in the range 600 to 1200 daltons.

Example 6

A collagen/ORC oligosaccharide sponge was prepared in the following way. Limed collagen fibres (0.8g) were slurried in 160ml 0.01 HCl (pH3.0), and 0.16g of ORC oligosaccharide, prepared as in Example 2 (molecular weight 1000-150000Da), was added. The mixture was homogenised for 15 seconds, HMDI was added (10% w/w of collagen) and the slurry was homogenised for a further 2 x 15 seconds. The slurry was degassed, poured into two 9cm diameter petri dishes, frozen and freeze dried using a heat ramp running from -30° to 70°C over 72 hours.

The collagen/ORC oligosaccharide sponge was then tested for its ability to bind platelet-derived growth factor (PDGF). For comparative purposes, Interceed™ fabric and a simple collagen sponge (prepared as described above, but without the addition of ORC oligosaccharide) were also tested. In each case, a small section of test material (approximately $1cm^2$ squares of Interceed™ fabric, and approximately 1cm x 0.5cm x 0.4cm sections of sponge) were weighed and soaked in 100mM sodium phosphate dibasic buffer containing 150mM sodium chloride (total volume 1ml) for at least one hour at room temperature. Samples were then incubated with 2% bovine serum albumin (BSA) in phosphate buffered saline (PBS) for 2 hours at room temperature. 25ng of PDGF was then added to each sample in 250µl of PBS containing 2% BSA, and samples were then incubated for a further hour at 37°C.

Each sample was then washed three times with 250µl PBS followed by increasing concentrations of sodium chloride. Finally, each sample was washed with 4.0M urea. ELISA analyses of the original PDGF preparation and the various washings from the sample materials provided the following results:

TABLE I: BINDING OF PDGF-AB

SAMPLE	COLLAGEN	COLL/ORC	INTERCEED
Original	100%	100%	100%
Unbound	20.6%	22.9%	15.4%
PBS wash	1.8%	11.1%	7.5%
0.3M NaCl	4.50%	12.3%	1.9%
0.5M NaCl	22.0%	22.2%	7.7%
1.0M NaCl	11.9%	15.2%	11.2%
2.0M NaCl	3.0%	5.1%	7.8%
3.0M NaCl	0%	4.3%	3.4%
4.0M urea	0%	4.0%	9.7%
Recovered	63.8%	97.1%	64.6%

The results show that the three test materials all bind similar quantities of PDGF, but PDGF can be recovered in highest yield from the collagen/ORC oligosaccharide sponge.

The binding characteristics are also uniquely different for the collagen/ORC oligosaccharide materials compared with the individual comparison materials. These observations indicate the complex has unique binding of PDGF which may be utilized appropriately for both exogenous binding and endogenous binding and release of growth factor.

CLAIMS

1. An oxidized oligosaccharide composition having an average molecular weight in the range 1000 to 50000 daltons.

2. An oligosaccharide composition according to claim 1 derived from an oxidized bacterial or plant polysaccharide.

3. An oligosaccharide composition according to claim 1 derived from an oxidized animal polysaccharide or an oxidized synthetic polysaccharide.

4. An oligosaccharide composition according to claim 1, derived from oxidized cellulose or an oxidized cellulose derivative.

5. An oligosaccharide composition according to claim 1, derived from an oxidized derivative of dextran, gellan gum, xanthan gum, agar, starch, konjac, carrageenan, guar gum, pectin, carboxymethyl cellulose, methylhydroxypropyl cellulose, cellulose acetate, methyl cellulose, cellulose phosphate, ethyl cellulose, or inulin.

6. An oligosaccharide composition according to any preceding claim having an average molecular weight in the range 5000 to 25000 daltons.

7. A pharmaceutical composition for topical, oral or parenteral administration comprising an oxidized oligosaccharide composition according to any of claims 1 to 6.

8. A pharmaceutical composition according to claim 7, wherein the oxidized oligosaccharide composition is bound to a pharmacologically active peptide or protein.

9. A pharmaceutical composition according to claim 8, wherein the peptide or protein is a growth factor.

10. Use of an oligosaccharide composition according to any of claims 1 to 6 for the preparation of a composition for use as or in a wound dressing.

11. Use according to claim 8, wherein a pharmacologically active agent is distributed substantially uniformly throughout said wound dressing.

12. Use according to claim 11 wherein said pharmacologically active agent is an antibiotic, an antiseptic or a protein growth factor.

13. A method of preparing an oxidized oligosaccharide, the method comprising the steps of:
(a) treating an oxidized polysaccharide having an average molecular weight of at least 5000 with an aqueous alkaline solution at a temperature and for a period of time sufficient to result in partial hydrolysis of said polysaccharide; and
(b) recovering the resulting oxidized oligosaccharide from said solution.

14. A method according to claim 13 wherein the alkaline solution is a solution of an alkali metal hydroxide or bicarbonate.

15. A method according to claim 13 or claim 14 wherein the oxidized oligosaccharide is recovered from said solution by adjusting the pH to 7 or less using an acid.

16. A method according to claim 15 wherein the acid is a concentrated mineral acid.

17. A method of preparing a composition according to any of claims 13 to 16, the method comprising the steps of:
(a) providing an alkaline solution of an oxidized oligosaccharide;

(b) dissolving or dispersing a therapeutically active agent in said alkaline solution; and

(c) reducing the pH of said solution or dispersion to cause said oxidized oligosaccharide to be precipitated.

18. A method of preparing a composition according to any of claims 13 to 16, the method comprising the steps of:

(a) providing an alkaline solution of an oxidized oligosaccharide;

(b) dissolving or dispersing a therapeutically active agent in said alkaline solution; and

(c) removing the solvent from said solution or dispersion.

19. A method according to claim 18 wherein the solvent is removed in step (c) by freeze-drying.

The Patent Office

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Claims searched: 1-19 **Date of search:** 11 October 1996

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

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Other: Online databases: WPI, CLAIMS

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 188992	(REYCHLER) see Claims 1-3	13
X	EP 0676415 A2	(HOECHST) see Example 1	1, 4, 5
X	EP 0268885 A2	(AJORCA) see Example	1 at least
A	US 5414079	(BIOCONTROL) see Claim 1; Example 1	13
X	WPI Abstract Accession Number 94-354775/44 & JP 06 0279504		1, 2, 5, 13

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.